Climate Modeling Using High-Performance Computing

Center for Applied Scientific Computing

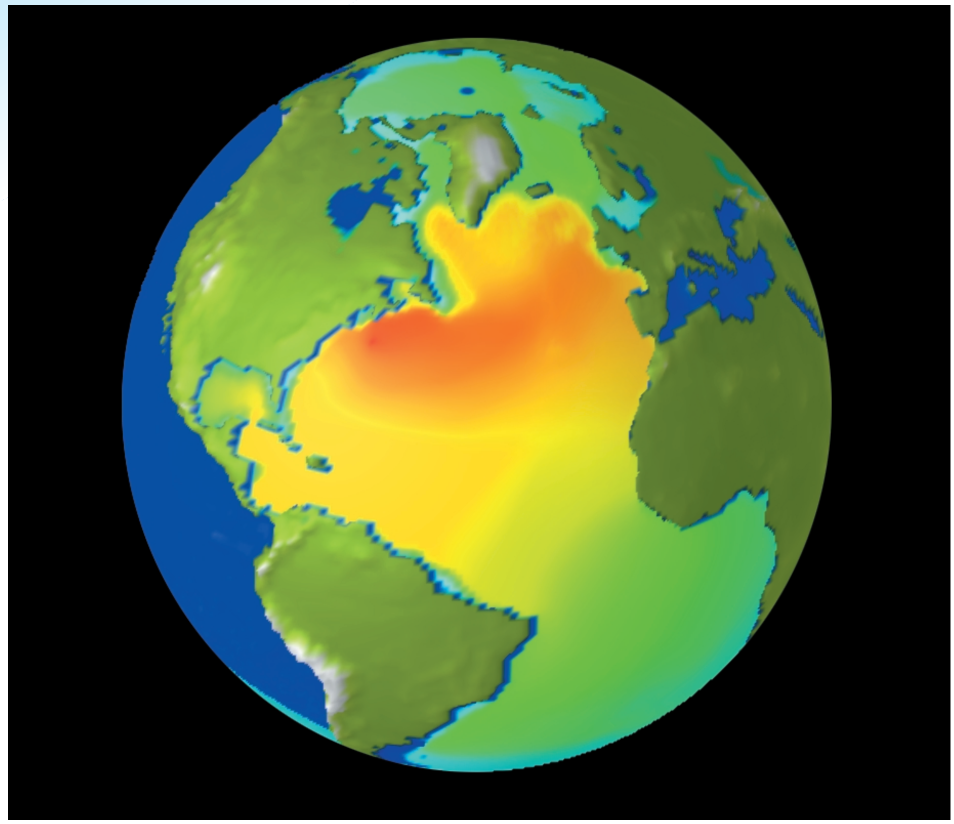

Figure 1: Simulation of ocean carbon dioxide concentration resulting from injection near New York City.

The Center for Applied Scientific Computing (CASC) and the LLNL Atmospheric Science Division (ASD) are working together to improve predictions of future climate by applying the best available computational methods and computer resources to this problem. Over the last decade, researchers at the Lawrence Livermore National Laboratory (LLNL) have developed a number of climate models that provide state-of-the-art simulations on a wide variety of massively parallel computers. We are now developing and applying a second generation of high-performance climate models.

Our collaborators in climate research include the National Center for Atmospheric Research (NCAR), Naval Research Laboratory Monterey, the National Aeronautics and Space Administration Data Assimilation Office (NASA DAO), Los Alamos National Laboratory (LANL), Lawrence Berkeley National Laboratory (LBNL), Argonne National Laboratory (ANL), Pacific Northwest National Laboratory (PNNL), and Oak Ridge National Laboratory (ORNL).

Current CASC/ASD Projects

Global Climate Model Development

As part of LLNL's participation in DOE's Scientific Discovery through Advanced Computing (SciDAC) program, members of CASC and ASD are collaborating with other DOE labs and NCAR to develop a comprehensive, next-generation global climate model. This model will incorporate the most current physics and numerics and will capably exploit the latest massively parallel computers. One of LLNL's roles in this collaboration is the scalable parallelization of NASA's finite-volume atmospheric dynamical core. We have implemented multiple two-dimensional domain decompositions, where the different decompositions are connected by high-speed transposes. Additional performance is obtained through shared memory parallelization constructs. In addition, LLNL has a leading role in adding to the model treatments of the carbon cycle and atmospheric chemistry.

Ocean Carbon Sequestration

A possible approach to delaying global warming is to "sequester" (store) greenhouse gases in the deep ocean. LLNL leads the numerical simulation effort for the DOE Center for Research on Ocean Carbon Sequestration (DOCS). CASC and ASD are performing model simulations of ocean circulation and carbon chemistry to assess the efficacy of this approach. In addition, we are developing improved numerical models that will be used to investigate this strategy. Figure 1 shows the simulated distribution of carbon dioxide after 100 years of continuous injection at 700 m depth off the coast of New York City, as computed by the LLNL/DOCS Ocean General Circulation Model. This is the highest resolution global ocean carbon sequestration simulation performed anywhere.

High Resolution Simulations of Global Climate

An important barrier to more realistic climate simulations has been the relatively coarse resolution used in global climate models. Due to the extreme computational demands of

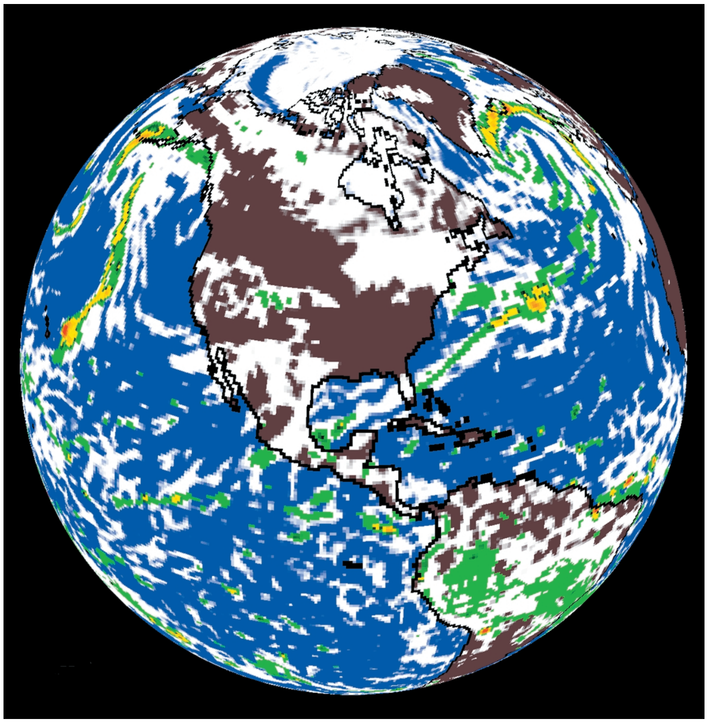

Figure 2: LLNL climate model simulation of precipitation (green) and cloudiness (white). This is a "snapshot" from a global simulation at 50 km resolution, the highest resolution global climate simulation ever attempted.

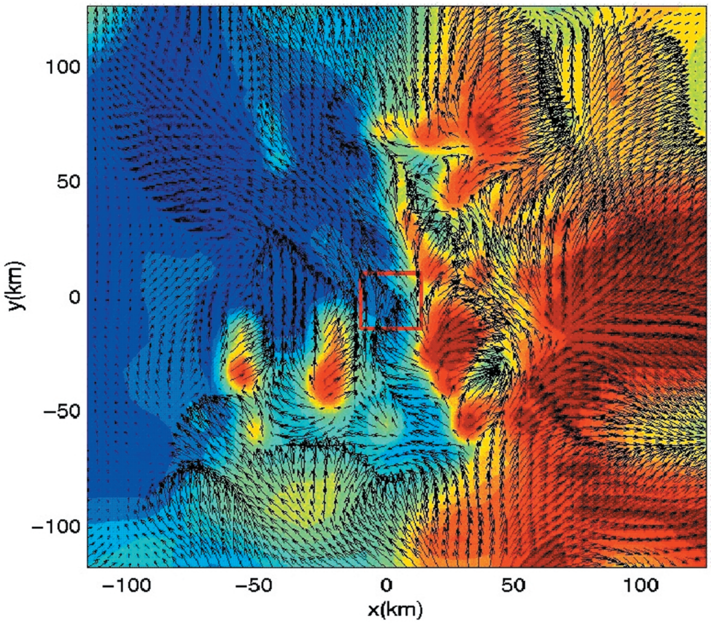

Figure 3: Near-surface winds in the Salt Lake City basin, as simulated by the COAMPS model.

global climate simulations, global climate models typically use resolutions of ~300 km. Researchers in ASD and CASC have recently experimented with running global climate models at resolutions as fine as ~50 km (Figure 2). These are the highest-resolution global climate simulations ever attempted and are made possible by LLNL's and DOE's extraordinary computing resources. As expected, these calculations produce more realistic simulations of many relevant quantities. Of particular interest is that the results in the fine resolution simulations can be more realistic even on scales that are resolved by the coarser-resolution models. Our experimental high-resolution simulations have demonstrated the feasibility of running global climate models at high resolution. In future work, we will use the high-resolution model to produce improved simulations of climate change on global and regional spatial scales.

Integrated Climate and Carbon (INCCA)

Today's three-dimensional climate models predict future climate by specifying future atmospheric concentrations of greenhouse gases and then calculating their radiative and climatic effects. A better approach is to specify greenhouse gas emissions—the quantity that energy policies control—and then calculate future concentrations and future climate. This approach requires incorporating detailed treatments of the carbon cycle and other biogeochemical cycles into climate models. Researchers in CASC and ASD are developing a comprehensive climate/carbon cycle model, which will be the first of its type in the United States. This model will be used to evaluate the climatic impact of proposed scenarios for greenhouse gas emissions and sequestration.

Regional Model Parallelization

In collaboration with the Naval Research Laboratory Monterey, CASC and ASD have parallelized the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) regional meteorological and climate model. The parallel model is being incorporated as an operational forecast model by both the Navy and LLNL's National Atmospheric Release Advisory Center (NARAC), which provides real-time assessments of the dispersal of hazardous materials. COAMPS is also employed as a research tool in the areas of weather forecasting, regional climate prediction, and urban modeling. Figure 3 shows near-surface winds in the Salt Lake City basin from a 4 km COAMPS simulation. The red square surrounds Salt Lake City. Terrain heights are indicated by the underlying color contours.

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